Nanocavity enhanced photon coherence of a quantum dot at up to 30 K

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Epitaxial quantum dots (QDs) have emerged as a leading platform for efficient, on-demand sources of indistinguishable photons, a key resource for many optical quantum technologies. To maximize performance, these sources normally operate at liquid helium temperatures (~4 K), introducing significant size, weight and power requirements that can be impractical for proposed applications. By experimentally resolving the two distinct temperature-dependent phonon interactions that degrade indistinguishability, we demonstrate that coupling to a photonic nanocavity can greatly improve photon coherence at elevated temperatures up to 30 K that are compatible with compact cryocoolers. We derive a polaron model that fully captures the temperature-dependent phonon effects, providing predictive power to further increase the coherence and operating temperature of future devices by optimizing cavity parameters [1].

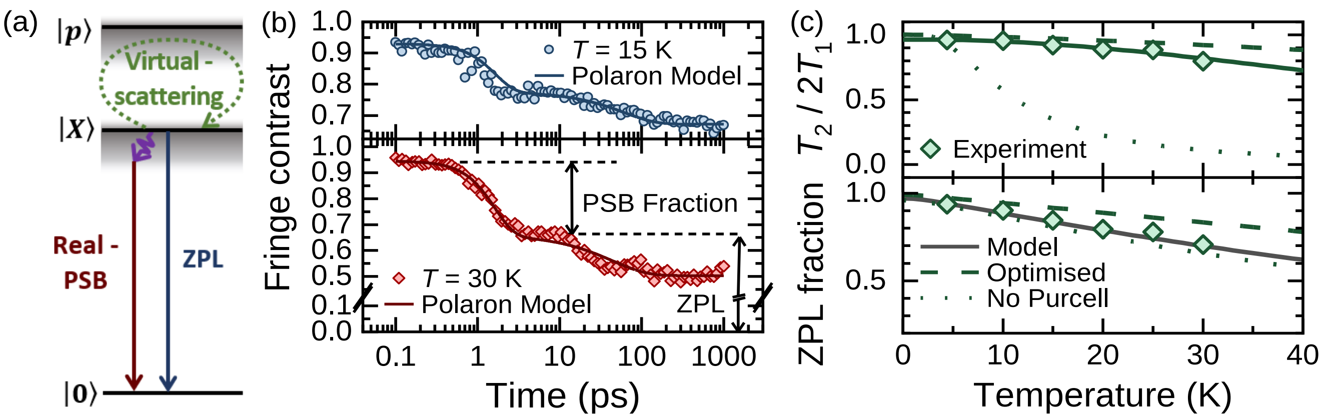

Fig.1. (a) Energy level diagram of the phonon-coupled QD exciton $|X\rangle$. (b) High-resolution time-domain measurement of the photon coherence of the QD-nanocavity system at T = 15 K (upper) and T = 30 K (lower). (c) Experimental (diamonds) and theoretical (lines) temperature evolution of the ZPL coherence ($T_2/2T_1$) and fraction.

Fig. 1(a) illustrates the two key processes that occur when the QD optical transition $|X\rangle \rightarrow |0\rangle$ is dressed by phonon coupling (grey shading). Radiative decay of the QD exciton (blue) produces the familiar zero phonon line (ZPL), however this can be broadened by dephasing from phonon-driven virtual transitions (green) to higher energy states $|p\rangle$. Absorption/emission of phonons (purple) also lead to real transitions (red), forming an incoherent phonon sideband (PSB) that reduces the ZPL fraction. To investigate these processes experimentally, we perform measurements on a resonant QD-nanocavity device with a large Purcell enhancement $F_P = 43$ [2]. High-resolution time-domain measurements of the QD photon coherence [3] independently resolve the influence of both real and virtual phonon transitions (Fig. 1(b)), allowing us to map out the temperature evolution of the ZPL coherence ($T_2/2T_1$) and fraction (Fig. 1(c)). Our polaron model (solid lines) closely matches the experimental results, whilst comparisons with previous studies and modelling without Purcell enhancement (short dashed line in Fig. 1(c)) illustrate dramatic enhancement of the ZPL coherence (>7x at 30 K) due to the large Purcell factor. Our results illustrate a pathway to indistinguishable QD photon sources at temperatures compatible with compact cryocoolers, a key objective for optical quantum technologies.

References

[1] A. J. Brash & J. Iles-Smith, Materials for Quantum Technology 3, 045001 (2023).

[2] F. Liu, A. J. Brash, J. O'Hara et al. Nature Nanotechnology 13, 835-840 (2018).

[3] A. J. Brash, J. Iles-Smith, C. L. Phillips et al. Physical Review Letters 123, 167403 (2019).